Virtual Technologies and Environments for Expeditionary Warfare Training

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Summary

Over the past decade, Virtual Environment (VE)-based training systems have become commonplace within the military training domain. These systems offer such benefits as small footprint, rapid reconfiguration, and enhanced training delivery. In addition, they appear to offer significant relief for a market starved for low cost training systems, and hold great potential as effective training tools. Yet, all too often the human element is taken for granted, with systems being designed to incorporate the latest technological advances, rather than focusing on enhancing the user's experience within the VE -both from a training and human factors perspective. It is precisely this shift in design philosophy, from techno centric to human centric that represents the next, greatest, challenge to developing effective VE-based training systems.

Interaction with VE involves the ability of individuals to effectively perform essential perceptual-sensory-motor tasks within the virtual world. More specifically, this can involve the ability to move about the VE, manipulate virtual objects, locate virtual sounds, deal appropriately with physical constraints, or perform visual tasks (i.e., discriminate colors; judge distance; search for, recognize, and estimate the size of objects). Interactive technologies include multi-modal 3D displays and input devices, real-time rendering, and distributed simulation (i.e., multiple user interaction through networked VE systems). These technologies define how the environment is portrayed and how it responds to user actions. The design, synthesis, and analysis of new interaction technologies will be based on our growing understanding of human perception and action in VEs. Tools are needed to provide a more comprehensive assessment of the quality of interaction.

The Office of Naval Research's Virtual Technologies and Environments (VIRTE) Program was developed to address this design challenge. VIRTE is focusing on developing two capabilities central to applying VE technology to training: (1) improving the quality of interaction provided by VE, and (2) applying advanced training aids and methodologies to real Navy and Marine Corps requirements. Quality interaction is essential for making VE usable for extended training and for applying VE

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technology to build combat simulators. Advanced training aids and methodologies are being developed to derive full benefit from the flexible new medium of VE.

Our approach takes maximum advantage of the growing knowledge base in human-centric design to build systems that are well-suited for enhancing performance of real-world tasks. In addition to traditional Knowledge Acquisition and Knowledge Engineering approaches, our interdisciplinary development team is utilizing team task analyses, motion sickness evaluations, and usability analyses. The team has also developed a novel methodology for evaluating team-based performance enhancement in VE systems. This cross-disciplinary approach gives the team a unique perspective into designing effective, low cost, deployable simulations. The technology testbeds that are being developed are useful not only for stand-alone training, but also for embedded training, team training, and mission rehearsal.

Introduction

Virtual Environment training Systems

Throughout the past decade, the United States military training community has turned its focus to Virtual Environment (VE) technologies as a means for providing rapidly deployable, easily configurable, affordable training solutions. As a result, a veritable barrage of (VE)-based training systems have been developed as potential solutions to a range of training requirements. While these systems typically offer the latest, cutting edge visual and hardware technologies, all too often the human element is taken for granted (Cohn, Breaux, Nguyen Schmorrow, 2001). A direct result of this techno-centric design philosophy is that the effectiveness of these systems is all too-rarely objectively evaluated. Consequently, the likelihood of designing a final product with a strong 'gee whiz' factor, combined with, at best, an undefined 'training effectiveness' quotient, is quite high, leading users to over-estimate the value of their training. In the operational setting, these over-estimations can have costly –if not tragic- consequences.

Human-centric Design Principles

Yet this need not be so. In parallel to the quantum leaps made in the technology realm, human factors specialists have made significant strides in developing human-centric design methodologies for ensuring that training systems satisfy the needs of the users for whom they are intended. The crucial element that has been missing is an underlying philosophy linking these techniques in a logical fashion.

Real World Example

Virtual Technologies and Environments (VIRTE)

The positive impact resulting from implementing these principles is best illustrated through an example of an actual VE training program, the Office of Naval Research's Virtual Technologies and Environments (VIRTE) Program. VIRTE spans several levels of simulation and will ultimately provide a networked, deployable system for training a myriad of concepts relating to a specific type of warfare known as Expeditionary Warfare. Expeditionary Maneuver Warfare (EMW) … "is the union of our core competencies; maneuver warfare philosophy; expeditionary heritage; and the concepts by which we organize, deploy, and employ forces" (Department of the Navy, 2001). Naval Expeditionary Maneuver Warfare consists of military operations mounted from the sea, usually on short notice. They are carried out by forward-deployed or rapidly deployable, self-sustaining naval forces tailored to achieve a clearly stated objective. The future primary platforms for Expeditionary Warfare, known as the "Amphibious Assault Triad", are the Landing Craft, Air Cushion, or LCAC, the Advanced Amphibious Assault Vehicle (AAAV), and the Osprey MV-22 tilt-rotor aircraft. VIRTE focused on these diverse vehicles since they present unique simulation and training challenges, as well as a component contributed by the United States Marine Corps, supporting Close Quarters Battle.

Within the VIRTE program, a range of simulations are currently under development. Each of these systems is based on real-world operational requirements and each is intended to transition to real world use as shown in Figure 1.

Figure 1: VIRTE focuses on providing deployed training solutions to the Expeditionary Warfare community. This community includes air, land and sea elements. *From Far Left to Right Top Row:* Landing Craft Air Cushioned (LCAC); Advanced Amphibious Assault Vehicle (AAAV) The MV-22 (Osprey) is a tilt-rotor craft currently under development; Close Quarters Battle. *From Far Left to Right, Bottom Row:* Virtual Environment (VE) LCAC; Virtual Environment (VE) AAAV; Virtual Environment (VE) MV-22; Virtual Environment (VE) CQB.

Landing Craft Air Cushioned (LCAC)

The LCAC is the only member of the triad that is currently fielded. The LCAC is a high-speed, over-the-beach fully amphibious landing craft capable of carrying a 60-75 ton payload. It is used to transport weapons systems, equipment, cargo and personnel from ship to shore and across the beach. The Navy has 76 LCACs in service. The LCAC crew consists of three positions, the Craftmaster (pilot), the Navigator, and the Engineer who work closely together to operate the vehicle. Currently, there are two LCAC Full Mission Trainers (FMTs), one at Assault Craft Unit (ACU) 4 in Dam Neck, Virginia, and one at ACU 5 in Camp Pendleton, California. While these provide excellent high fidelity training, they are expensive to procure and operate. The LCAC fleet is just beginning to field a Service Life Extension Program (SLEP) which completely changes the operator interface to the vehicle. It will be several years until there are sufficient SLEP LCACs fielded to transition the FMT to the SLEP configuration.

Advanced Amphibious Assault Vehicle (AAAV)

The Advanced Amphibious Assault Vehicle (AAAV) is currently in the prototype stage and it is scheduled to enter Low Rate Initial Production in FY 07. The AAAV will provide the capability to move a combat loaded USMC rifle squad at over 20 knots on the water and maneuver cross country with the speed and agility of the M1 tank. It will replace the AAV7A1. The AAAV crew consists of the driver, the gunner, and the vehicle commander. The AAAV is in the System Development and Demonstration (SDD) phase and second generation prototypes are being matured and prepared for production. The AAAV will be supported by a significant investment in training systems. VIRTE is focusing on transferring technology to two of these, the schoolhouse training system and the vehicle embedded training system.

MV-22

The MV-22 Osprey is a tilt-rotor aircraft that will provide airlift in support of Expeditionary Maneuver Warfare. The tilt-rotor design combines the speed, range, and fuel efficiency normally associated with turboprop aircraft with the vertical take-off/landing and hover capabilities of helicopters. The MV-22 crew consists of a pilot and co-pilot. The MV-22 is currently in Low Rate Initial Production (LRIP) and in the USMC will replace the CH-46E and CH-53D. As with the AAAV, there is a significant investment in training systems. Rather than try to insert technology directly in the MV-22 program, we are concentrating on demonstrating technologies that are applicable to all aircraft trainers.

Close Quarters Battle Military Operations in Urban Terrain (CQB for MOUT)

CQB for MOUT is a type of urban warfare that is distinct from the commonly portrayed ‘jungle’ or ‘desert’ combat scenarios. In CQB for MOUT, small teams, typically in groups of 4, are tasked with clearing a building of enemy units, room by room. It is a type of warfare that is extremely hazardous and man-power intensive. Currently, there only two options for providing CQB for MOUT training. The first option is Live training, which involves moving these teams through mock-up villages (‘combat towns’) using simulated ammunitions. The second option is through the use of simple computer generated scenarios, involving the projection of scenes on a screen, with users navigating through the scenario using simple interfaces such as joysticks or footpedals.

Both training options have significant disadvantages. Live training has significantly reduced realism due to the numerous safety constraints imposed during such activities. As well, this type of training involves the use of pre-made building mock-ups which can not be easily reconfigured, greatly reducing the range of potential training scenarios. At the same time, the simulations currently in use also fail to provide a strong basis for performance enhancement. Current systems utilize non-natural Human-Computer Interfaces and therefore cannot teach tactical mobility skills. Further, the manner in which the computer-generated scenes are slaved to the user’s movement does not support the development of the ‘move-look-shoot’ philosophy crucial to this form of combat. Finally, although CQB for MOUT is a team-based activity, current training systems, which present one scene to an entire team, can not support any level of ‘individualized’ first person perspectives that is part and parcel of this combat environment.

Prototype Development

While the real-world analogues of each VIRTE component serve unique roles in actual combat and impose unique training requirement upon their operators, their efforts complement each other; standard military doctrine relies on elements from each to achieve the overall objective (Department of the Navy, 1999). In parallel, the virtual systems are designed with the dual purpose of supporting training at the individual level, as well as at the level of distributed, team-based events, operating within a shared synthetic battlepsace.

In order to develop a suite of VE-based training tools that supported each of these Expeditionary Warfare components, within the Department of Defenses’ modeling and simulation framework, several parameters had to be defined. First, the technologies underlying each VE system must be compliant with the US Department of Defense (DOD) High Level Architecture (HLA). Second, each of the simulations had to share the same virtual battlespace. Finally, since these systems were intended to transition directly to the users, VIRTE tried to minimize program license costs with the vision that of being able to hand out CD applications to anyone that wanted them. These requirements led to the selection of the government owned JointSAF as the simulation environment. OpenFlight was selected as the visualization database standard and allowed each of the development teams to choose their own tools. VIRTE's goals in this domain came closest to the vision with the VELCAC which uses a commercial gaming engine, Gamebryo (formerly NetImmerse). VIRTE Demonstrations II and III will all use Gamebryo.

Early prototypes were crucial to the program. In a two year span, VIRTE went from Demonstration I concepts to deployable prototypes. VIRTE developers employed a Spiral Development process and held a series of Intermediate Feasibility Experiments (IFEs). The four IFEs were events where developers deployed their latest configurations in realistic testing environments with potential users. All of the VIRTE simulations are PC based and interoperable in the same virtual battlespace. They have some unique differences based on customer requirements. The VEAAAV, which is a school house training prototype, has extensive replication of the physical layout of the crew stations. The VELCAC uses almost all virtual displays, with the exception of the "throttle" which has a unique feel and gives important haptic feedback to the craftmaster. The VEHelo is the only VIRTE Demo I simulator that uses a HMD in the deployed configuration. The VEHelo uses a Head Mounted Display (HMD) which combines the virtual environment and live video. Each of these approaches has tradeoffs and these are brought out in the Training Effectiveness Evaluation.

VIRTE Demonstration II, Close Quarters Battle for Military Operations in Urban Terrain (CQB for MOUT) has a much greater focus on "traditional" Virtual Environments. The most unique aspect of Demo II is that it puts a soldier directly into the virtual environment using his entire body and weapon as a means of interaction. Unlike First Person Shooter (FPS) games, which use keyboard commands or a joystick, VIRTE is prototyping technology which allows the user to naturally interact with the virtual environment either walking in a tracked space or walking in place. This level of interaction with the Virtual Environment presents exceptional challenges for Human Factors. For example, what is the best way to let a person know that they have put their hand through a virtual wall? How do we immerse an entire fire team and allow them to have natural interactions? In Demo II, the CQB training system, VIRTE is focusing significant investment into real time full body tracking, collision detection, distributed audio environments, and distributed Virtual Environments. The remainder of this paper discusses the process the VIRTE team has implemented to ensure that the training provided by each VE system provides a measurable level of performance enhancement on the real world tasks they are designed to support.

Training Effectiveness Evaluation (TEE)

In order to better understand the process implemented by the VIRTE team for ensuring training enhancement, the individual components comprising this user-centric design process were categorized as elements of a broader, Training Effectiveness Evaluation (TEE) effort. The philosophy underlying the development of a TEE plan includes:

- Up Front Analyses
  - Provide foundation for developing systems
- Iterative Integrated Feasibility Experiments
  - Provide iterative feedback for system developers
- Back end Analyses

– Final evaluation
– Lessons Learned

These three general elements can be operationalized as six component ‘building blocks’ which are:

- Task Analysis
- Human Computer Interface evaluation
- Team Performance
- System Usability
- VE User Considerations
- Training Transfer

The manner in which these pieces combine is somewhat fluid. In a broad sense, these pieces can be grouped into three general phases. Phase one consists of the Task Analysis and the Human Computer Interaction evaluation. The first element, the *Task Analysis (TA)*, seeks to identify the training objectives and the scenario elements that must be included in a simulation to support these objectives as well as providing an assessment of whether currently available training can be modified so that a technology solution is not necessary. For TEE purposes, a contextual task analysis is performed, which focuses on the behavioral aspects of a task as performed in a given operational setting, resulting in an understanding of the general structure and flow of task activities (Mayhew, 1999; Nielsen, 1993; Wixon & Wilson, 1997). The second element *Human-Computer Interactions (HCI)* focuses on identifying the requirements for sensory modality integration, as well as evaluating current hardware/software technologies supporting these interactions, and providing guidance for integrating them into a simulation. Once these efforts are completed, the information is then passed on to the Simulation Developers, who may then commence their efforts.

The second phase involves an iterative evaluation process, in which the system is evaluated at key points within the development lifecycle. These points, termed Integrated Feasibility Experiments are points at which the TEE team can evaluate progress along the dimensions determined in phase 1. There are two key portions to this phase. The first is *System Usability*, which evaluates how accommodating the overall VE design is for use by the layperson (Stanney, Mollaghasemi, & Reeves, 2000) and provides redesign recommendations to the developers. The second is *VE User Considerations,* which addresses both evaluations of the side effects encountered during exposure to VE, as well as aftereffects arising following this exposure.

The final phase focuses on performing a system-wide evaluation, and then documenting these findings in a ‘lessons learned’ format. Since all the training systems under development for VIRTE focus on crew or team-based application, the first component of this effort is Team *Performance*, which addresses how well a simulation supports team-based activities (Cannon-Bowers, & Salas, 1998). Perhaps the most important element of TEE, which validates all the efforts described thus far, is an evaluation of the degree to which *Training Transfers* from the VE to the real world scenario (Carretta & Dunlap, 1998; Lathan, Tracey, Sebrechts, Clawson, & Higgins, 2002; Waller, Hunt, & Knapp, 1998). Figure 2 provides an overview of how these components can be integrated into a comprehensive TEE plan.

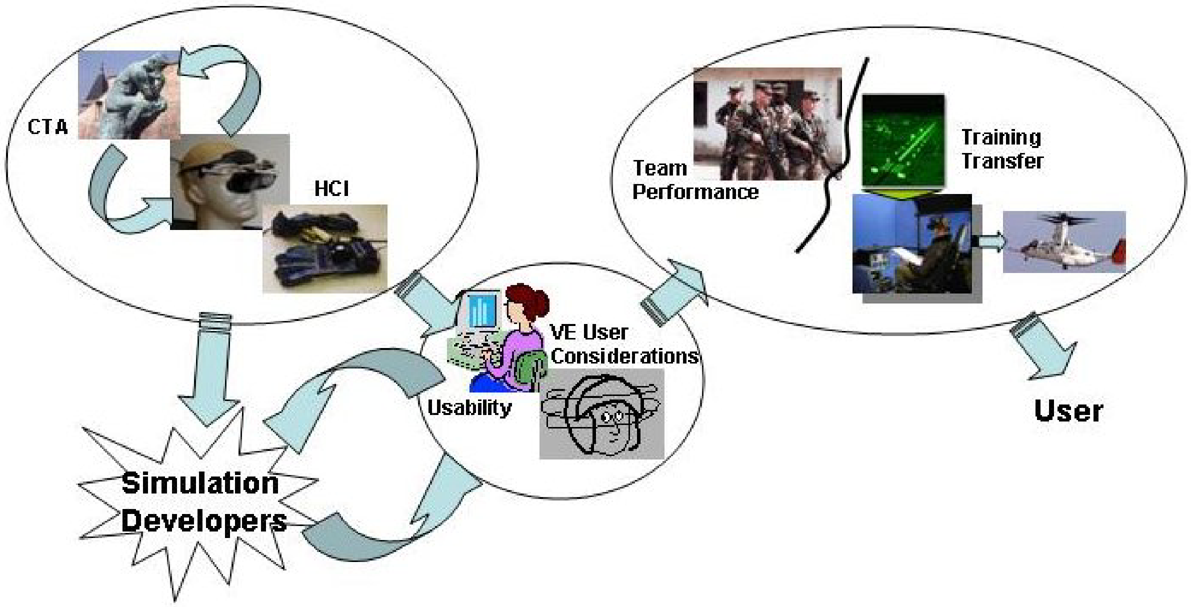

Figure 2: Schematic of elements comprising the VIRTE Training Effectiveness Evaluation, and the relationship/flow structure linking them.

As Figure 2 suggests, TEE is not simply a process that is performed once, at any single stage in the design of a VE simulation. Rather, as with traditional usability engineering practices (Nielsen, 1993), it must be interwoven throughout the entire design process. Moreover, each of the proposed TEE elements is intertwined with the others. Ultimately, the six aspects of TEE should combine to form a seamless, continuous, evaluation of the overall VE training simulation, leading to a well thought out, well-designed system that will enhance training while reducing the cost of providing this training. The research objectives of VIRTE were structured so that, while each VE platform utilized aspects of each TEE component, each platform was also singled out to highlight, from the science and technology perspective, issues and applications within these elements.

Task Analysis

One of the most basic challenges that any VE developer faces, prior to designing a new VE simulation is *How to design a system that will support the users' training needs?* The commonly accepted approach for answering this question is to conduct a task analysis. While there are many types of task analysis (Chapman, Schrage, & Smith, 2001), it is possible to select one basic methodology by understanding the characteristics of the user community. VIRTE is concerned with providing experts with training on abstract concepts rather than with training novices to perform specific perceptuomotor tasks, hence a *cognitive task analysis* (CTA).

Through this effort, training objectives and evaluation metrics were developed for each platform. Considering the training of the LCC community, it was determined early on that the VELCAC system's primary use would be as a teaching supplement to acquaint highly skilled crews with a new cockpit instrumentation layout and corresponding upgraded features (the Service Life Extension Program, or SLEP, LCAC configuration). The resultant CTA identified those features of VELCAC that would best complement the SLEP differences course, a two-week training course designed to acquaint crewmembers with the new LCAC features. The key training objective for the VE AAAV was identified as being the provision of a gunnery training system. Hence, the task analysis focused on techniques for providing real time and after action feedback to enhance speed and accuracy of this task. The focus of the VE Helo system was on providing enhanced training for visualizing spatial relationships in preparation for low level, Nap of Earth (NOE) flight. Consequently, the VE Helo task analysis focused on identifying the cognitive components of route learning and navigation. Finally, the intended use of the CQB training system is to provide a means for maintaining skill proficiency during extended deployments, as well to provide an interactive, three-dimensional mission rehearsal system. The CQB task analysis focused not only on core skills and cognitive components of basic CQB maneuvers, but also on understanding tactics and strategies that the Opposing Forces (OpFor) might use.

Human Computer Interaction

The overall goal of the HCI evaluation is to identify, based on the CTA, which modalities (haptics, visual, sound, etc.) must be represented within the VE to in order to provide an effective training experience. Since the bulk of the VIRTE systems are vehicle- based, the two primary senses under consideration are vision and haptics. Although much work has been done exploring the visual modality, the integration of haptics within a VE simulation represents a unique challenge because, unlike vision (and audition), the haptic system provides both sensation/perception and the means to manipulate.

The bulk of VIRTE's HCI effort focused on the VELCAC system. Several sources of information were examined during this evaluation. These included a requirements document, user profiles, results from user interviews, the TA, field observations, and knowledge of the operational environment. In addition, a literature review examining performance issues relating to visual displays and haptic systems was conducted. The analysis of this information provided a set of criteria by which decisions regarding visual and haptic displays could be made. Critical information derived from these sources suggested that of the three crew positions under consideration, only the Craftmaster (the crewmember who flies the LCAC) would need physical controls (yoke, foot pedals, and throttle) in the VELCAC and a wide field of view, in order to maintain adequate situational awareness while piloting the (virtual) craft. The other two crewmembers (the Navigator, who monitors instant position, and the Engineer, who monitors LCAC system function) spend the majority of their time observing and interacting with touch screen interfaces on the instrument console. Consequently, the final version of VELCAC utilized a panoramic-like, flat-screen based visual display. The Craftmaster position was provided with the actual controls interfaces, while the other two positions were provided with an interface to their instruments based on using a mouse to point and select specific options.

Usability

System usability focuses on evaluating how accommodating, intuitive and easy-to-use software and hardware are for use by the layperson. The assessment of a system's usability typically involves an initial expert evaluation of the system to identify any design weaknesses in the prototype system, which includes an observational assessment of users interacting with the VE, an analysis of these data to identify which features are less-than optimal and why and, the development of a set of ranked and ordered redesign recommendations for system developers to follow. As should be apparent Usability evaluation is most useful when it is incorporated as part and parcel of an iterative design and development process.

As an example of how this iterative process works, during each IFE the usability assessment of the VELCAC began with an expert evaluation of the current version of VELCAC, conducted by two usability engineers. This assessment was then followed by user observation, by these same experts, of LCAC crewmembers interacting with various SLEP VELCAC stations. The results of these efforts were used to provide redesign recommendations, as well as to establish/validate usability metrics and their associated acceptability criteria for future usability testing of SLEP VELCAC as more mature iterations of the system are developed.

VE User Considerations

Typically, the impact of Virtual Environments on users has been typified in terms of a collective group of symptoms known as Cybersickness. Operationally, the majority of the research into these symptoms has focused on acute symptoms, such as eyestrain and blurred vision, rather than on a more holistic approach, which would focus on impact on warfighter readiness. Yet, as the military continues its push towards using VE systems to provide just in time training (Cohn, Muth, Schmorrow, Brendley & Hillson, 2002), it is becoming increasingly evident that this level of research will be the one most critical for evaluating the utility of using VE systems. Currently, the military has restrictions delineating the amount of time an individual must wait between exposure to simulated training and participating in the actual real world effort.

For the purposes of VIRTE, whose simulators target Naval forces and may ultimately be placed aboard ship (Cohn et al, 2002), a critical concern is the sensory decoupling that arises between the visually indicated motion reference frame, provided through immersion within the VE, and the physically indicated motion reference frame, provided through the (moving) platform of the ship. Such sensory discordance may be particularly troublesome, both during training as well as following training. Preliminary results (Cohn et al., 2002) suggest that in this situation side effects, such as motion sickness will result. VIRTE is actively pursing two solutions to this sensory discordance challenge. The first focuses on developing technology to re-introduce the coupling between physically sensed and visually indicated motion. The physically indicated motion of the ship is locked to the motion of the entire framework of the virtual scene being displayed through the VE in such a manner that a trainee experiences both the intended, virtual motion, as well as a degree of motion recoupling. Preliminary results suggest that this approach holds promise (Brendley, Marti, Cohn & DiZio, 2002). At the same time, it is crucial to quantify the impact these decouplings have on warfighter readiness. Consequently, VIRTE is developing a Warfighter Readiness Toolkit that combines cognitive, perceptual and physiological evaluation tools that can detect subtle changes that might lead to deleterious side effects that could impact warfighter readiness.

Team Performance and Training Transfer

Ultimately, each of the previously mentioned efforts are useful only to the extent that they are able to support the primary goal of developing *any* VE simulation, namely, to provide a level of training that translates to enhanced performance of the real world task being simulated (Lathan et al., 2002). Despite the fact that VE systems continue to be pushed into the training application domain, there are few convincing illustrations of the transfer of complex skills from VE training to their corresponding real-world applications (Cohn, Helmick, Meyers & Burns, 2000). A critical limiting factor in most such efforts is that they fail to utilize adequate performance metrics, relying instead on users' anecdotal evaluations or perceptions of training utility rather than statistically determined measures. Thus most results are difficult to interpret both in terms of the underlying *processes* that lead to either positive or negative transfer, as well as in terms of the meaning of *outcome*.

The most common approach for assessing training transfer is to compare performance between two groups of trainees, an experimental group that receives simulator training and a control group that receives all of its training in the real world, along some predefined set of metrics (Boldovici, 1987; Cohn et al., 2000; Murdock, 1957). It is important to note that while it may be possible, in a general sense, to develop standard approaches for this effort, ultimately, the metrics thus developed will be context specific. Thus, for each type of VE system, it is critical to identify differences in process and outcome behaviors between individuals who receive VE training and those who do not receive that training when performing operational tasks in the real world environment.

Importantly, for purposes of a transfer study, each of the real world platforms being simulated through VIRTE involves interactions between team members. Consequently, measures of changes in team processes (e.g., exchange of information, backup behaviors during times of high workload) serve as a critical measure of training effective and directly impact the degree to which training will transfer. At the same time, more task specific, outcome measures should also improve, such as improved timing (e.g., at checkpoints and way-points) and accuracy (e.g., less discrepancy between actual and planned speeds and course), which should occur if there is positive transfer of training from the VE to the real world.

Summary

While many elements of Virtual Environment development are platform specific, it is possible to distill a set of principles, which if followed, should translate to a more effective training system. These principles can be implemented early on, as part of the task analysis and human computer interaction evaluation efforts and can continue, throughout the development lifecycle as a usability and user consideration assessment. Ultimately, the success of these efforts will be established through a comprehensive training transfer study.

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